

parture was in Kansas, and the high-level cell was almost directly overhead.

Maj. E. H. Bowie has drawn my attention to an article by George Reeder which appeared in the MONTHLY WEATHER REVIEW of October 1919, entitled "The Rela-

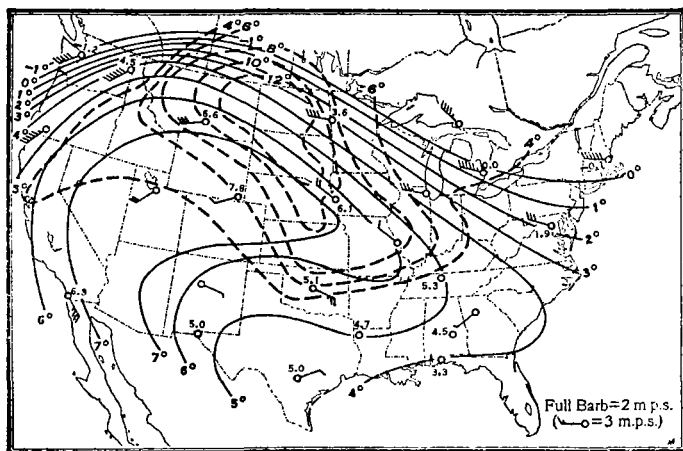


FIGURE 8.—July 1936. A month of unusual heat and drought in the Middle West. Solid lines indicate isotherms at 4,000 m., °C.; broken lines, departures from normal temperature at surface, °F.; resultant winds at 4,000 m.

tionship between Cirrus Movements from Easterly Points, and the Occurrence of Severe Droughts," in which the author showed that during severe droughts in summer in Missouri, and preceding them, "the cirriform clouds show a persistent though very sluggish movement from easterly points." Lacking free-air data, Mr. Reeder endeavored to account for this abnormal cloud movement by a study of surface pressures. It is quite likely that had he possessed the information which we now have regarding air circulation at high levels he would have attributed the

phenomenon to other causes, for the easterly winds over Missouri could occur only when the high-level anticyclone was far north and east of its normal position. Figures 8 and 9, just considered, may be taken as an example of an air structure probably approximating situations of the kind he described. It will be noted that in each case there was a northwest resultant wind over the upper Mississippi Valley, countered further south by a southeast resultant wind over Oklahoma. Note, too, the close agreement between resultant winds and isotherms, and how the high-level circulation has apparently maintained an air mass of

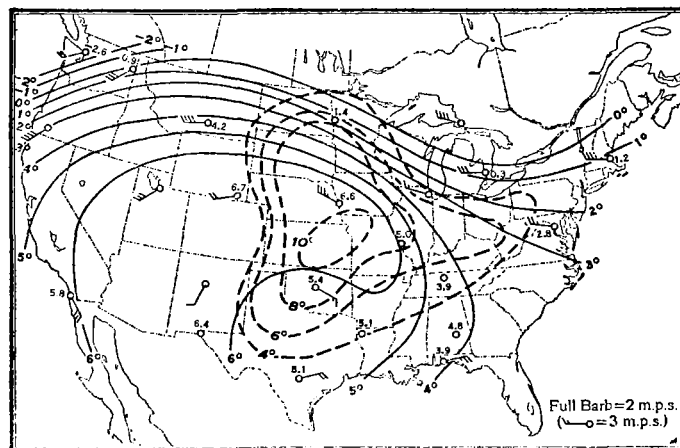


FIGURE 9.—August 1936. A month of unusual heat and drought east of the Rocky Mountains. Solid lines indicate isotherms °C. at 4,000 m.; broken lines, departures from normal temperature at surface °F.; resultant winds at 4,000 m.

abnormal warmth far eastward over the Mississippi Basin, and hence an atmospheric structure hostile to convection.

Special thanks are due Messrs. Little and Samuels of the Aerological Division of the Weather Bureau for help in providing data for some of the charts herewith.

## FURTHER STUDIES OF AMERICAN AIR-MASS PROPERTIES

By ALBERT K. SHOWALTER

[Weather Bureau, Washington, June 1939]

These studies originally were undertaken for the purpose of bringing up to date the mean values of the characteristic air-mass properties of North America as first given by Willett (1). This seemed desirable in view of the large mass of airplane sounding data obtained since the publication of Willett's paper, which was based principally on kite observations. A preliminary analysis of the new data indicated that some minor changes in Willett's classification of air masses might be necessary. A more thorough study, however, based also on certain synoptic considerations, led to the abandonment of the absolute system of classifications, for reason that will be stated later; and the conclusion was reached that Bergeron's differential classification, which was used by Willett as an alternative system, forms a better basis for air-mass definitions.

The relation between the two classifications can be seen by listing and comparing them as follows:

### *Absolute classification (adapted from Willett)*

- Pc—Polar continental air which, after becoming modified, is called Npc (transitional polar continental).
- Pp—Polar Pacific, and the modified form Npp.

PA—Polar Atlantic, which, when modified, becomes NPA.

TA—Tropical Atlantic, which in the charts and cross sections used for this study, included both the TA and TG (tropical Gulf) masses of Willett's classification, since both of the air masses come out of the subtropical anticyclone cell of the Atlantic.

Tr—Tropical Pacific.

Tm—Tropical maritime, a designation used when it is impossible to determine whether the air mass is of Atlantic or Pacific origin or when the two are mixed.

S—Superior, which includes all air masses which appear warm and very dry because, principally, of subsidence and divergence. S includes the type of air mass labeled Tc (tropical continental) in Willett's original publication and Ts (tropical superior) in later treatises by the same author (2).

Np—Modified polar, which is air definitely of polar origin but of doubtful continental or maritime origin, or a mixture of continental and maritime polar air. This type of air mass, which was not definitely classified by Willett, forms the predominant polar air mass of summer.

**NPM**—Modified moist polar; air which has become very moist (high relative humidity, moderately high temperature) by any of several possible means—by a long history over water, by precipitation through it, by evaporation into it from the surface, by mixing with **Tm** air, or perhaps in some cases by cooling, either radiational or dynamic. This classification is not very desirable from a geographical standpoint, but for practical purposes it was used at first in the study. It included the terms *Np becoming Tm*; *NPPM*, *NPP becoming Tp*; *Npc becoming NPA*, *NPA*, *Np+Tm*; and similar terms employed on synoptic charts and cross sections. The **NPM** designation does not appear in Willett's classification.

#### *Differential classification (adapted from Bergeron) (3)*

This classification implies the existence of two fronts separating three air masses—the Arctic front between Arctic and polar air, and the polar front separating polar from tropical air; the intertropic front does not enter into the scheme of things as far as the United States is concerned. The Arctic front, through southward migrations of the cold air, becomes a polar front, at which stage a new Arctic front usually is created, at least in winter. The minor cold and warm fronts, occluded fronts, etc., of middle latitudes are sections of the polar front; in fact under ordinary conditions the polar front is not a single, continuous front, although frequently it is approximately so.

**cAw**—Continental Arctic air, warmer than the surface over which it lies (stable in the low layers). This corresponds to the pure **Pc** air mass at its source.

**cAk**—Continental Arctic air, colder than the surface over which it is passing (steep lapse rate in the lower layers). This corresponds to pure **Pc** air that is moving rapidly and undergoing convectional or mechanical convergence around (usually behind) an intense cyclone in high latitudes.

**MAK**—Maritime Arctic air, colder than the surface over which it is passing (steep lapse rate). This corresponds to a mixture of **Pc** and **Pp** air masses flowing together rapidly down the Alaskan Pacific coast toward the United States, producing a type of weather somewhat distinct from that produced by the usual **Pp**.

**cPw**—Continental polar air, warmer than the surface over which it is passing (stable in the lower layers). Corresponds to stable **Npc**, **Pp**, or **NPP** modified over the continent, the latter type sometimes classified as **NPPc** [see Byers (4)].

**cPk**—Continental polar air, colder than the surface over which it is passing (steep lapse rate). Corresponds to **Npc**, **NPPc**, and **Np** that have been heated from below, especially in summer.

**mPw**—Maritime polar air, warmer than the surface over which it is passing (stable in the lower layers). Corresponds to a return current of **Npp** over the ocean (**NPPM** according to Byers) or **Pp** becoming **Npp** by rapid cooling in the valleys and basins of the Far West in winter. Sometimes also corresponds to a return current of stable **NPA**, or **NPM**.

**mPk**—Maritime polar air, colder than the surface over which it is passing (steep lapse rate). Corresponds to fresh **Pp** and some forms of **NPP**, **PA**, and **NPM**.

**mTw**—Maritime tropical air, warmer than the surface over which it is passing (stable in the lower layers). Corresponds to certain types of **TA**, **TP**, and **NPM**.

**mTk**—Maritime tropical air, colder than the surface over which it lies or is passing (steep lapse rate). Corresponds to **TA**, perhaps occasionally also **TP**.

Superior air (**S**) is not of surface origin and is the same in both classifications. Continental tropical air does not appear in North America.

The outstanding characteristics of the various air masses may be outlined as follows:

#### WINTER SEASON

##### *Continental Arctic Air*

As shown by Willett (1) and Wexler (5) **cA** air is probably formerly maritime polar air (**mPk**) which is cooled by surface radiation forming **cAw**. A study of this air mass by Wexler has shown that there is a very sharp inversion near the surface, and above, a lapse rate approaching the isothermal. The rapid increase with height of potential temperature as shown for **cAw** air in figure 2 illustrates the exceptional stability of this air mass. Since the effect of surface cooling rarely extends above 3 km. above sea level, the uncooled air above would still be **mP** and very few observations of **cA** air are available above that level. Occasionally **cA** air is mechanically lifted to 4 km. at Cheyenne and in such a case it will be cooled adiabatically and a temperature very low for that height will result. Unstable Arctic air, **cAk**, sometimes occurs in the Hudson Bay and the Great Lakes regions but insufficient data are available to include **cAk** air in this study.

The modifying influences affecting **cA** air are principally the addition of heat and moisture at the surface and a tendency for subsidence aloft. A complete discussion of **cA** (**Pc**) air and other air masses is contained in Willett's paper and it is the author's intention to avoid needless repetition of the important modifying influences. The change in designation from **cAw** to **cPw** has been more or less arbitrary but usually one or two days elapse before **cAw** air is considered **cPw**. A more definite criterion for the change in notation is the formation of a new Arctic front. Eventually the original polar air may become tropical air, so **cPw** merely marks the transitional stage.

The striking thing in the movement of **cAw** becoming **cPw** air into the southern United States is that the steepening of the lapse rate which would be expected from the addition of heat from below does not occur in the mean, except in the lowest few hundred meters. Apparently subsidence proceeds so rapidly at all levels above the shallow turbulent-convective layer that the great stability characteristic of **cAw** air near its source is still preserved and **cAw**→**cPk** is rare, except behind deepening cyclones. As the polar air feeds into low latitudes it spreads out to occupy several times its original area and thus the compensating subsidence shown by the various charts and tables is accounted for.

The properties of **cPw** air, as would be expected, are about midway between the properties of Arctic and Tropical air.

There seems to be considerable moisture added in the lower levels by surface evaporation but because of the extreme stability of cAw and cPw air it does not seem likely that the effects of surface addition of moisture extend to any appreciable elevation. Consider for example, the mean value of 2.2 g./kg. for specific humidity with a potential temperature of  $288^{\circ}\text{A}$ . at 2 km. at Oklahoma City in cPw air. (See fig. 2.) To establish an adiabatic lapse rate to carry such a quantity of moisture up to 2 km. by vertical convection, a potential temperature of  $288^{\circ}\text{A}$ . is required at the surface. Since a surface potential temperature of  $288^{\circ}\text{A}$ . is found only in air of

air mass, and employing a pseudo-adiabatic diagram, it is found that the assumed conditions result in a specific humidity of 2.8 g./kg., and an equivalent-potential temperature of  $280^{\circ}\text{A}$ . If vertical convection with constant equivalent-potential temperature obtained to 5 km. above sea level in such an air mass the temperature at 5 km. would be about  $-43^{\circ}\text{C}$ . The lowest temperature observed at 5 km. in mAk air was  $-43.4^{\circ}\text{C}$ . at Spokane on February 7, 1936. It must be borne in mind that the above are minimum values of the properties of mAk air and most of the outbreaks do not result in such low values. In fact the mean values here summarized are much too

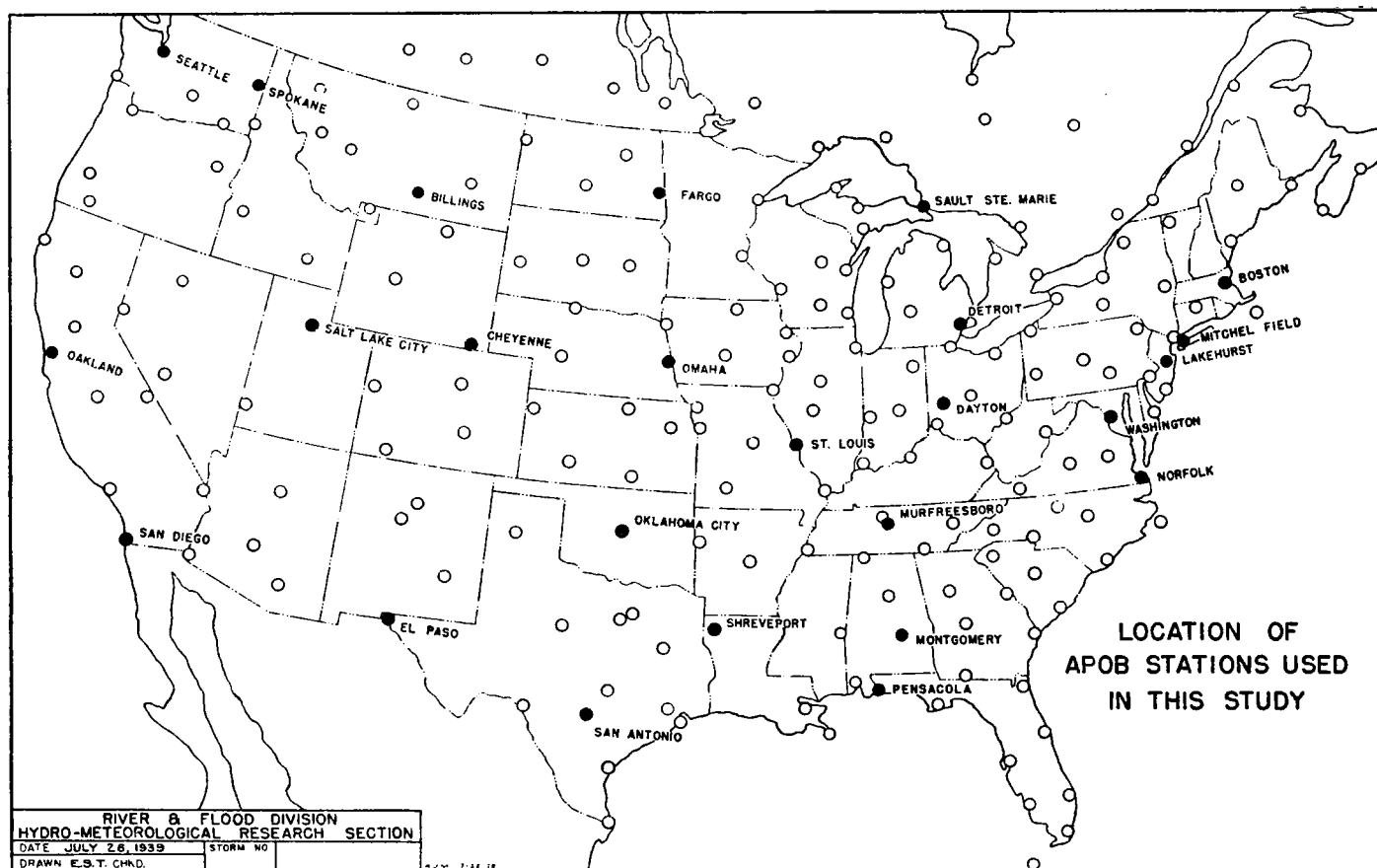


FIGURE 1.

very nearly tropical properties it is evident that the observed amount of moisture could not have been carried up to that elevation by simple vertical convection. The addition of moisture at higher levels in modified polar air is probably best explained by the theory of horizontal mixing along isentropic surfaces as discussed by Rossby (6).

#### *Maritime Arctic air, mA*

When an outbreak of polar air moves over only a very small part of the Pacific Ocean before reaching the United States it is usually designated as mAk. If its trajectory has been far to the south, it usually is sufficiently modified to be called mP. Since mA air must have properties closely resembling those of cA air before moving out over the ocean it is possible to estimate the minimum values of its various properties. Assuming a pressure of 1,000 mb. at the surface, which is a reasonable value for a winter mA current, a minimum temperature at the surface of  $0^{\circ}\text{C}$ . and 75 percent of saturation as would be expected in this

high for typical mAk air. The means were obtained from sampling of air originally classified as Pp. They represent observations of mAk, mAk→mPk or mPw, and mPk→mPw. Strictly speaking, for air masses entering the United States, the notation mAk should be reserved for Arctic air masses which move directly southward along the North Pacific coast and have only a short trajectory over the ocean. The notations mPk and mPw are adequate to differentiate between maritime polar outbreaks having longer trajectories. (See fig. 7.) The unusual instability of mAk air, some flights indicating that vertical convection has obtained to at least 6 km., has two important effects on its interaction with other air masses in the central and eastern part of the United States. First, since often it is colder aloft than the surrounding air masses, sinking from these levels, or subsidence, occurs in mA and mP air. Second, and inversely, this same instability in mA air is apt to cause an increasing tendency for vertical divergence and increasing instability in air masses moving into a region occupied or recently occupied by mA

air. In other words, the mA gains in stability while the surrounding masses lose.

During the winter months mA air near the surface is usually warmer than the continent, and shortly after passing the coast line it becomes a warm type air mass according to the Bergeron classification. Over snow covered areas mA air very rapidly assumes continental characteristics; thus we find the modified form of mA air sometimes colder near the surface than the original.

Because of the mountain ranges in the western part of the United States and the presence at the surface of cold continental air, most of the Pacific air masses in winter move eastward over the continent without reaching the surface, except in certain unusually warm winters.

The effects of surface modification on polar Pacific air masses over the United States are but slight in the winter months except as the air masses approach the more southerly stations. The mean values for mP air cannot be

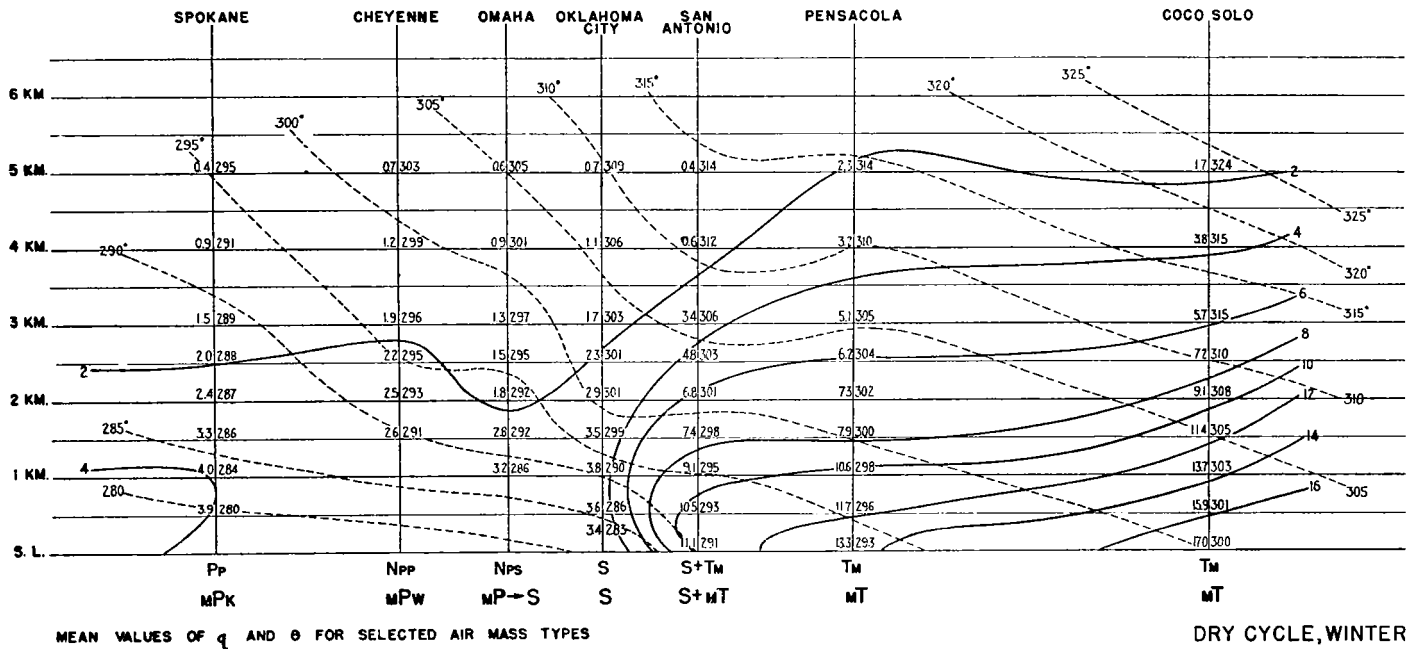


FIGURE 2.

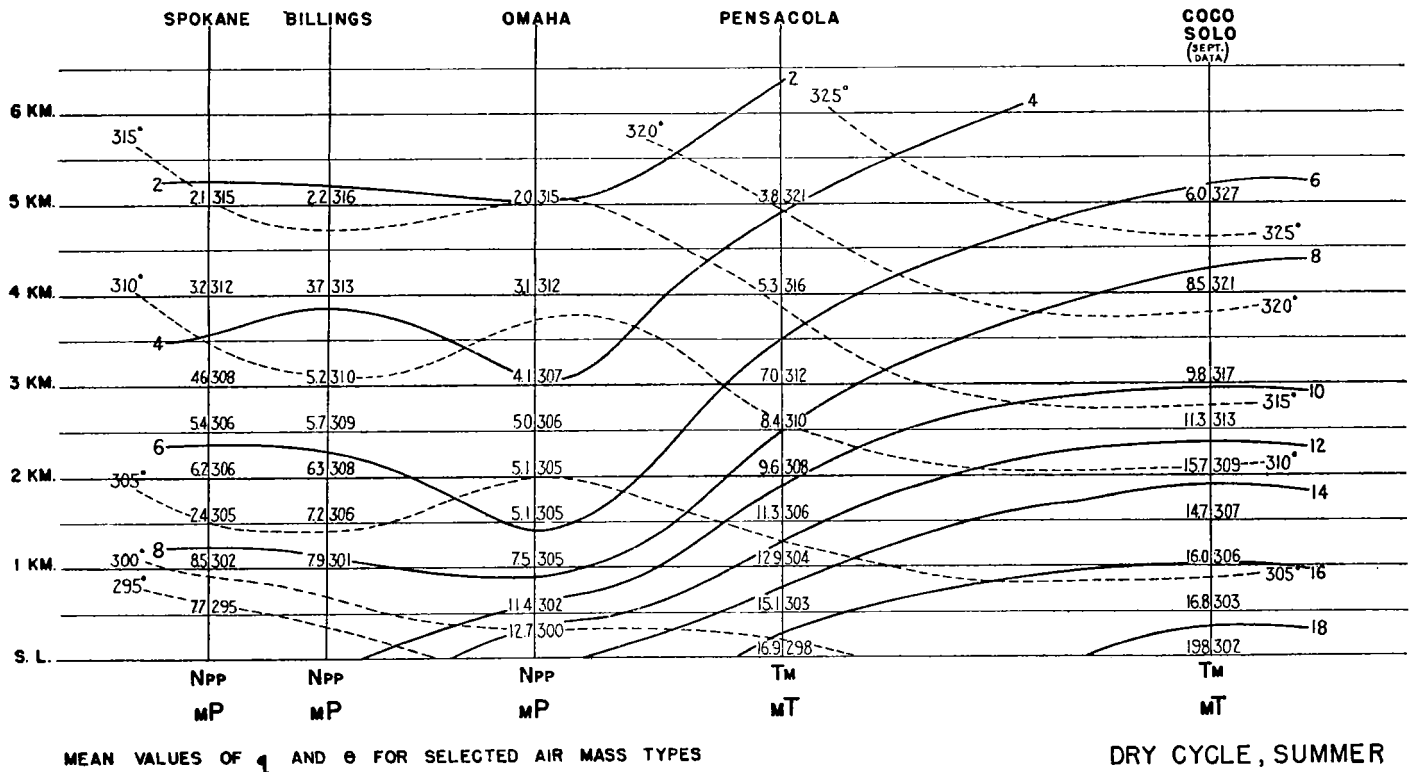
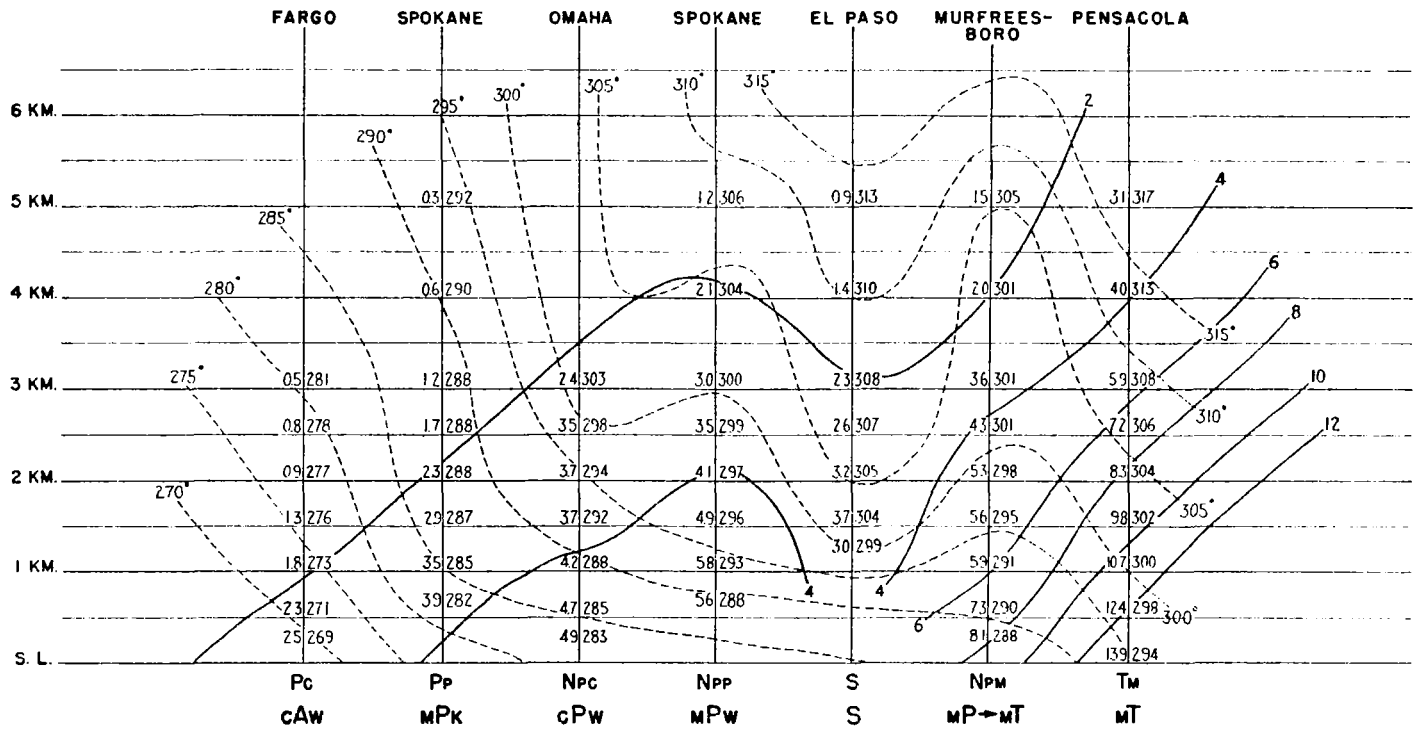


FIGURE 3.

MEAN VALUES OF  $q$  AND  $\theta$  FOR SELECTED AIR MASS TYPES

( SPRING 1936)

FIGURE 4.

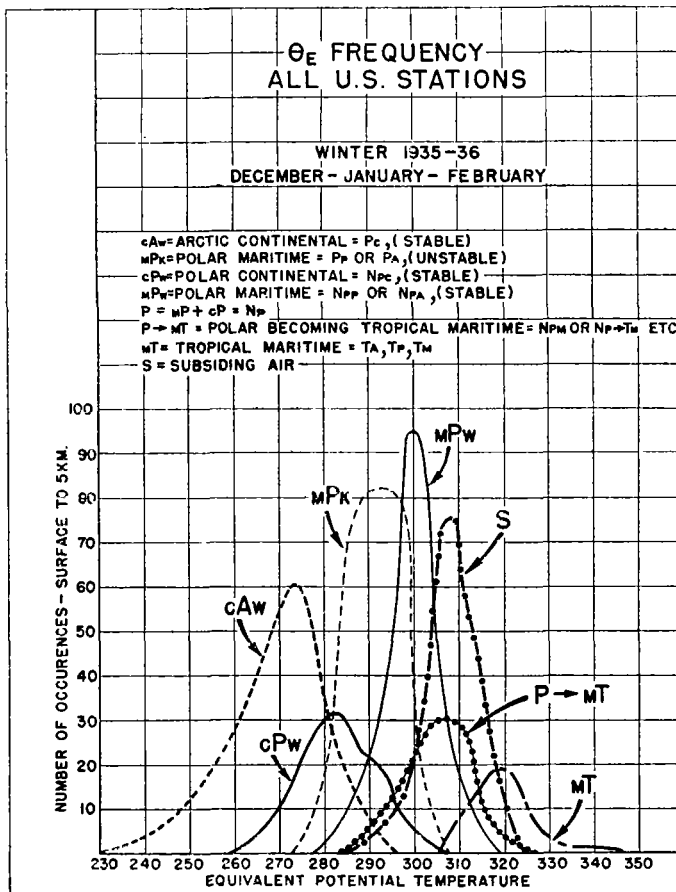


FIGURE 5.

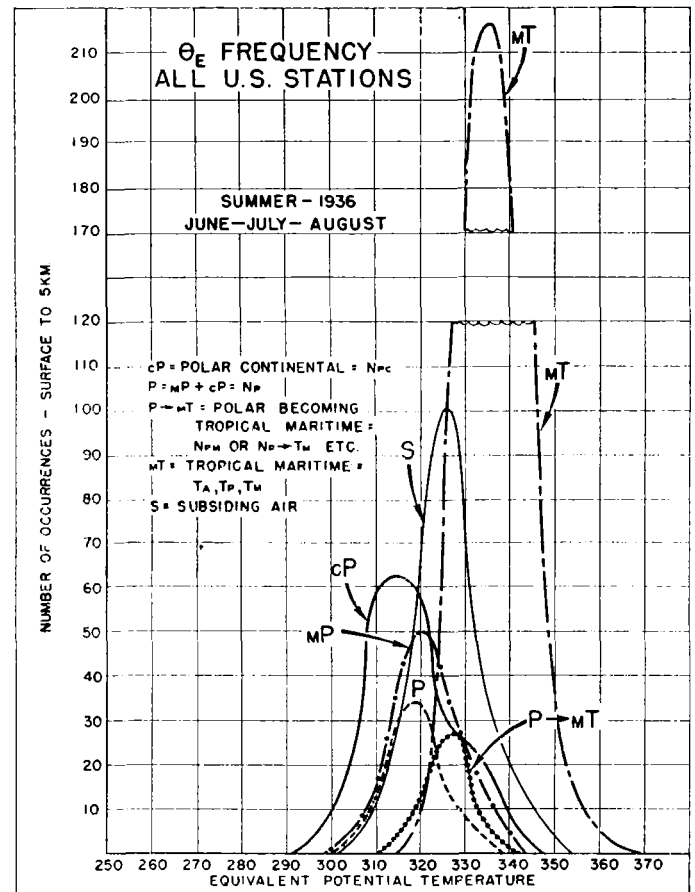


FIGURE 6.

Form No. 1145A—Aer.

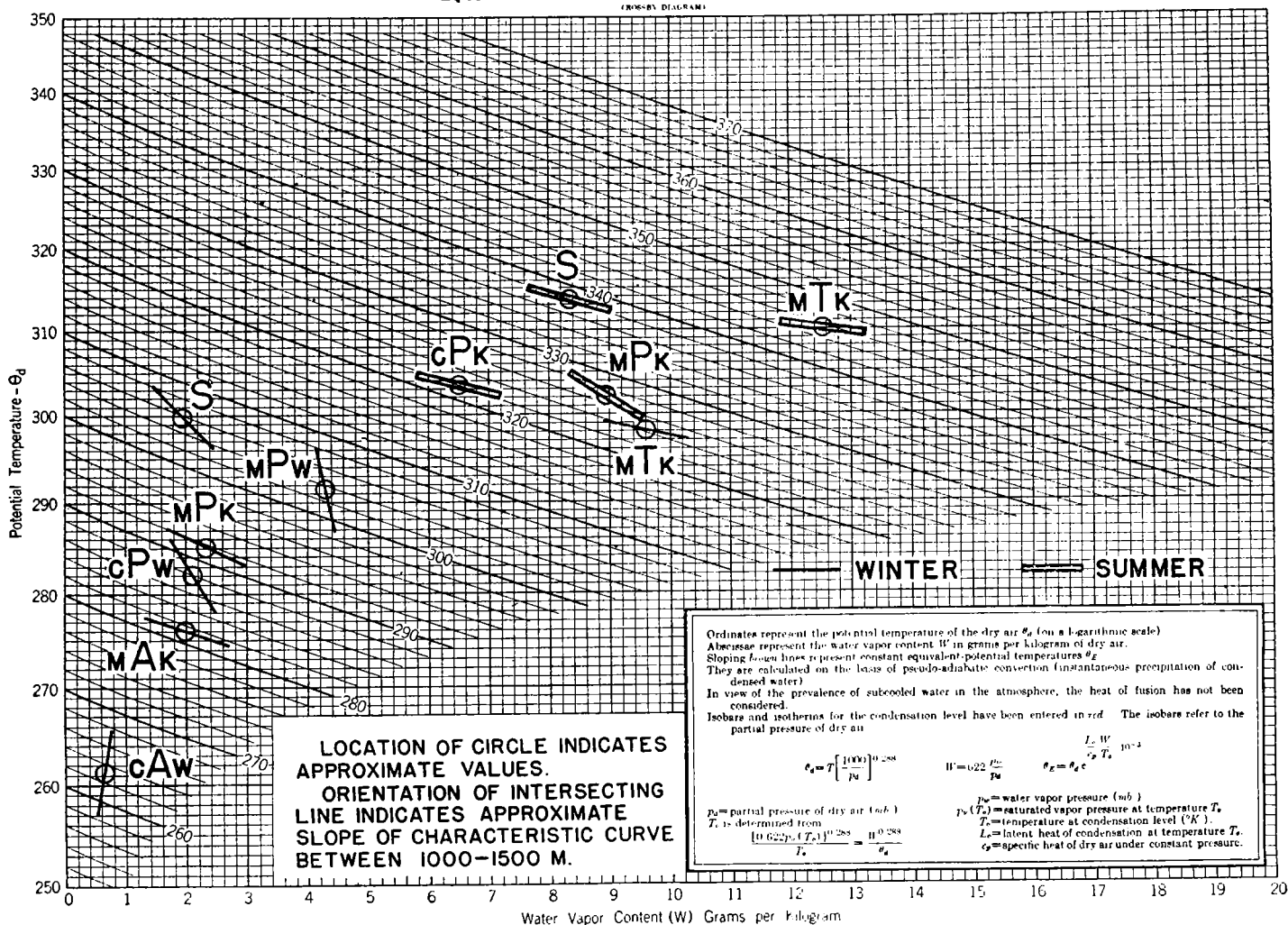
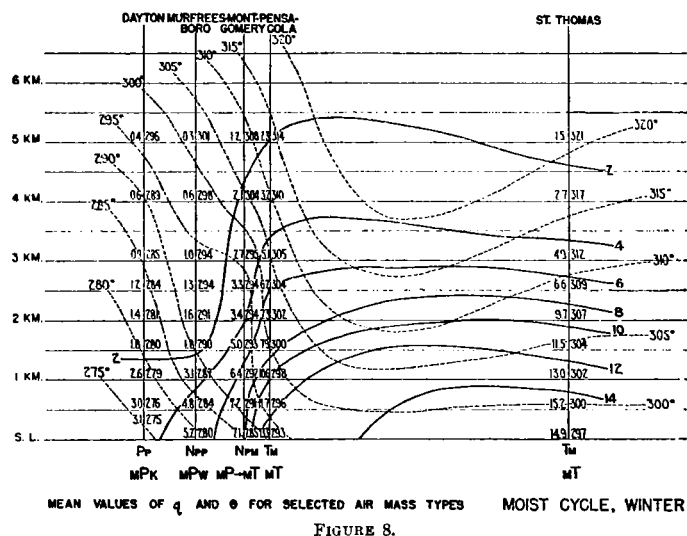
 U. S. DEPARTMENT OF AGRICULTURE WEATHER BUREAU  
 EQUIVALENT-POTENTIAL TEMPERATURE DIAGRAM  
 (CROSS-BY DIAGRAM)


FIGURE 7.

considered representative of the effects of continental modification; first, because the notation mP is also applied to air masses which have had a trajectory far to the south over the Pacific Ocean; second, because of the tendency for subsidence in Polar Pacific air, a large number of samples of the modified form of this air mass have been classified as S air in the course of this study; third, because a few samples of modified Pacific air which were rapidly assuming tropical maritime characteristics were summarized under a special group. It seems safe to say that some of the increase in moisture at higher levels cannot be explained by vertical transport and must be explained by isentropic mixing.

Samplings of maritime polar air from the Atlantic, and its modified forms are quite rare in the winter months because this type of air mass is usually off the New England coast, and when it does move inland its tendency for instability and saturation usually results in conditions too hazardous for flying. The few samplings available in this and other studies indicate that Polar Atlantic air in



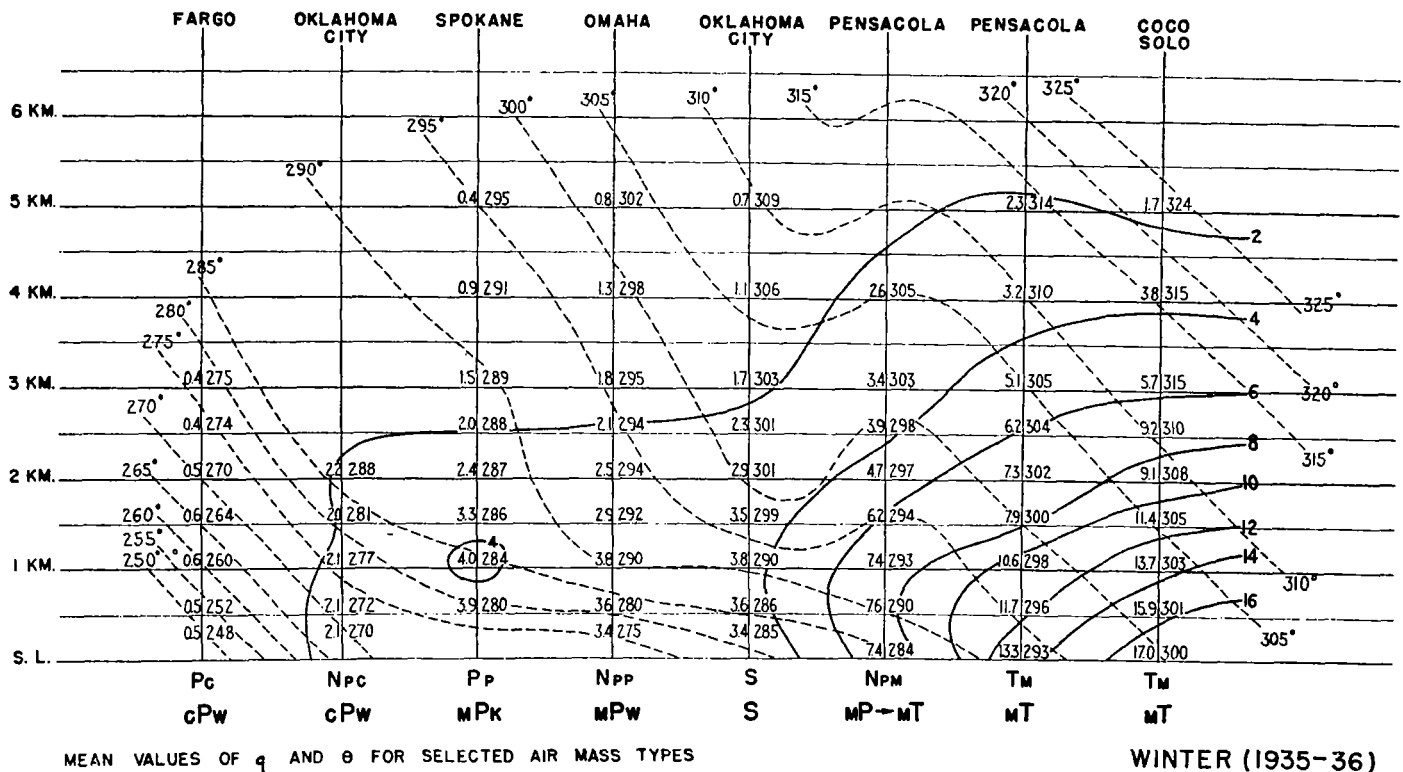


FIGURE 9.

general develops the same distinguishing properties as Polar Pacific but vertical convection has not reached to such great heights.

#### Maritime tropical air mT (T<sub>m</sub>)

It is unfortunate that only a few soundings in mT<sub>w</sub> air were made during the winter selected for this study; but since the source region for mT air exhibits only minor variations from one year to the next, even a few samplings of mT<sub>w</sub> air can be considered representative of its general characteristics. Since mT air is formed out of air which was originally polar, it shows a tendency for vertical stability with some subsiding action in the higher levels. It will be noted that although the partial-potential temperature of the dry air increases fairly rapidly with elevation, the equivalent-potential temperature usually decreases with elevation. This seems to indicate that at higher levels this air mass is relatively dry. Since mT air usually moves inland with anticyclonic motion it may be assumed that the relative dryness aloft in mT air can be explained by horizontal divergence with subsidence in the upper levels of the subtropical anticyclonic cell. There is evidence that some of the water vapor at higher levels must have been carried upward by vertical convection over scattered areas in the Gulf and Caribbean, and was diffused to the surroundings. The evident upward slope of the isentropic surfaces to the northward indicates that the moisture is carried aloft not only by vertical convection but also by isentropic mixing. The upward transport of moist air appears to occur near the edges of the subtropical anticyclones, while the subsiding dry tongues originate nearer to the centers.

Due to the lack of adequate history for the trajectories of tropical maritime air entering the western part of the United States, it is difficult in most cases to identify positively T<sub>p</sub> air masses as such. From a comparison of

average surface temperatures over the Pacific Ocean and the Gulf and Caribbean area (7, 8), it seems that an air mass would have to move about 5° of latitude farther to the south to attain comparable amounts of heat and moisture over the Pacific. The persistence of the anticyclone off the California coast with very dry air aloft

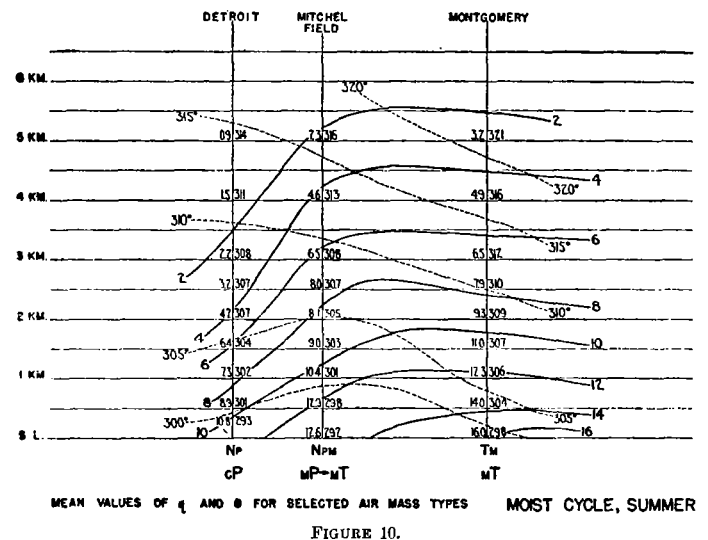


FIGURE 10.

seems to demand that in any northward movement, tropical Pacific air would be exposed to likelihood of both horizontal isentropic mixing and mechanical vertical mixing with much drier air. Not enough samplings of T<sub>p</sub> air are available to show definitely that it possesses any characteristics distinct from tropical Atlantic air. The values obtained for Manila by Deppermann (9) seem to agree well with the values obtained for Coco Solo and St. Thomas in this study.

*Superior or subsiding air S (Ts)*

The notation Ts (tropical superior) was originally applied to air supposed to have been derived from the upper subsiding portions of the subtropical anticyclonic cells (2). However, of recent date the designation S has been applied to all warm air masses that show relative humidities below 40 percent, which is taken as an indication of subsidence and horizontal divergence. The study indicates that most of the dryness results from the subsidence of high level air from a polar source. Isentropic analyses have shown definitely that a number of dry tongues move out from polar regions. Consider for example the potential temperature surface of 302° A.; mP air shows an average specific humidity of 0.8 g./kg. for that surface, and mT air an average of 7.3 grams. The average value of 2.0 g./kg. given for S air at this surface indicates that the main source of the dryness in S air is probably the upper levels of the polar air, but that the average also

the air moves along potential temperature surfaces (10, 6), and since the mean values represent a large number of saturated conditions it is impossible to differentiate between the effects of vertical convection and isentropic mixing in NPM air.

## SUMMER SEASON

*Continental polar air cA→cP (Pc→Npc)*

As explained by Willett (1) surface conditions in the source region of cA air in the summer are considerably different from winter conditions. Both the mP and cP are originally Arctic air masses and have similar properties at their source, but undergo different influences on their journey to the United States. cA→cP air undergoes very rapid surface heating and slow addition of moisture. Since so few cases of cA air have been classified as such it is safe to say that during the summer months all out-

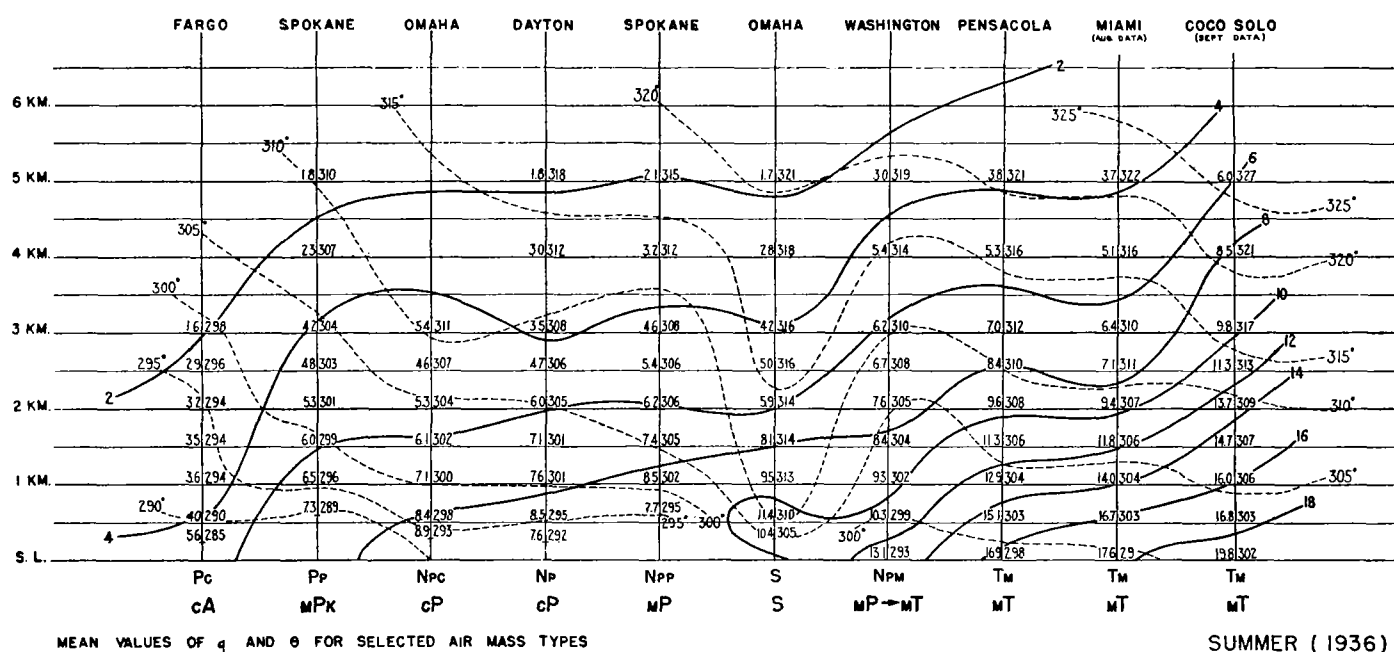


FIGURE 11.

includes a number of cases of air of tropical or subtropical origin as well as cases of isentropic mixing between air from tropical regions and subsiding air of a polar source. Further studies of the general circulation on the basis of isentropic charts may show that all dry air aloft, even in the tropics, comes from high latitudes.

*Modified moist Polar air mPw (NPM)*

All of the various types of modified polar air which were rapidly becoming warm and moist were grouped under the heading of NPM for purposes of this study. The mean values for these air masses show a tendency for decreasing stability and increasing moisture content. Although there is evidence that considerable heat and moisture are added by surface effects, there must be an addition of moisture aloft by isentropic mixing. The fact that a large number of NPM soundings show humidities at or near saturation makes it impossible to make quantitative estimates of the effects of addition of moisture at the surface. In other words, conditionally stable air under saturation conditions moves along equivalent-potential temperature surfaces, and prior to saturation

breaks of cold continental air are sufficiently modified to be labeled cP by the time they reach the United States. Because most of the flights are taken before sunrise the mean values for cP air show great stability up to 2 km. As noted by Willett (1) there is a large diurnal range in the temperature in continental air during the summer months so that by midafternoon on clear days most of the stability in the lower 2 km. has been removed. The rate of increase of moisture aloft seems slightly in excess of that possible through vertical convection and it is necessary to believe that horizontal mixing plays an important role.

*Maritime polar air mA→mP (Pp→Npp)*

The source of mA air is originally Arctic, but its trajectory over the Pacific Ocean leads to a fairly rapid increase in moisture. However, because of the cool waters of the Pacific and the small diurnal range in temperature over the water, the addition of heat is slower than it would be over the land. As soon as the maritime air mass moves inland it is heated very rapidly. Further, because of the usually long maritime trajectory, polar Pacific air masses



are quite warm as a rule by the time they reach Spokane or Billings, so it is usually advisable to use the notation mP during the summer months.

Although it is not so pronounced in the summer time, the tendency for subsidence in Pacific air masses moving across the Rockies has about the same general effect as it has during the winter months. There is a rather large diurnal temperature range in mP air over the land and apparently considerable moisture is added by vertical convection in the lower levels.

The effects of subsidence and outflow from the upper portions of mP air seem to have about the same prominence as the effects of horizontal mixing so the mean values for mP air do not give positive evidence of the increase of moisture aloft by isentropic mixing.

The notation cP or Np should be used in cases of doubtful history of the polar current, or in cases of overlapping layers of maritime and continental air having been thoroughly mixed by vertical convection during the day or in some cases by mechanical turbulence. Since there is so little difference in the properties of mP and cP after 1 day's history over the continent during the summer months it would be wise to label all polar air masses cP in the summer time, after they have moved east of Spokane and south of the Canadian border.

#### *Modified moist polar air mP (NpM)*

This group, as in winter, includes all polar masses which are rapidly assuming tropical maritime characteristics. The rapidly increasing moisture seems to be a combination of the effects of surface evaporation over water surfaces or areas with abundant plant life, coupled with the effects of horizontal mixing. It seems possible therefore for a polar air mass with a purely continental history to attain in summer quantities of heat and moisture comparable to those obtained by an air mass moving over the Caribbean Sea.

#### *Maritime tropical air mT (Tm)*

The source region and characteristics of tropical Atlantic air are about the same in summer as in winter. The effect of continental modification is reversed in summer, however, and the air mass is heated rapidly at the surface as it moves inland and mT air masses very frequently become unstable during the day. It appears that in general the potential temperatures are higher in mT air than in continental air masses and that therefore the air would move upward along the isentropic surfaces as it came over the land. Some of the cases studied indicate that at times a given isentropic surface may slope downward from the Gulf to the continent. This means that portions of the mT column may at times move downward in approaching the continent. It will be noted that mean potential-temperature surfaces are approximately horizontal between Miami and Pensacola.

Taking the vertical distance in meters between the 303°A. and the 311°A. surfaces as an inverse measure of stability, one finds the mT air to be more stable in the mean than mPk air but less stable than cPw air. This agrees with the statement made during the discussion of mP air wherein the author stated that mP air was likely to cause increasing instability in air masses moving into its territory. The author is of the opinion that it can be statistically proved that the greatest probability of rain occurs when mT air replaces mA or mP, or when mA or mP replace mT air. The latter sequence is more conducive to precipitation during the colder seasons.

Samplings of tropical Pacific air were not included for the summer season since such an air mass is extremely rare over the United States during that season and has no properties different from other maritime tropical air masses.

#### *Superior or subsiding air (S)*

The assumption that the dryness of this air mass is due to subsidence is not necessarily correct in summer, because rapid surface heating of relatively dry air at that season may produce a deep column of air whose moisture content is far from the saturation values. When such an air mass is cooled during the night by surface radiation some slow sinking may occur in the layers near the surface and those layers which are not cooled by radiation will show low relative humidities by the time of the airplane observation the next day. Since S air is recognized only on the basis of relative humidities less than 40 percent, the source of this air can therefore be traced to subsiding polar or tropical air or to rapid daytime heating of either type.

The range in specific humidity and equivalent potential temperature is considerable at all elevations for the dry type of air called S, so it can be assumed from this evidence also that the source of S air can be either polar or tropical or a stratification of air from both sources with a tendency for horizontal mixing along the isentropic during the night and vertical convection during the day resulting in a dissipation of the concentration of moisture. The orographic effect also plays an important role in the development of S air east of the Rocky Mountains.

#### AIR MASS CLASSIFICATION

The above discussion has treated mainly the important identifying characteristics of each type of air mass for the winter and for the summer months based in general on Willett's classification. Data have also been computed for the spring and fall seasons and are published here, figures 13 and 15. The study indicates that it is possible to make some reasonable standardization of air mass classification for synoptic purposes but that any classification falls far short of definitely identifying the thermodynamic properties of the different air masses. In other words the mean values of each of the various properties (see figs. 12 to 15) show definite groupings for the different air masses, and the individual values show definite limits for the properties of fresh tropical and fresh polar outbreaks. However, the modifying influences affecting air masses and the almost arbitrary method of classifying air masses, especially in the summer months, result in a very wide range of equivalent-potential temperatures as indicated on the frequency distribution charts (figs. 5 and 6). It can be seen from a study of these charts that the classification is relative for any one day, and no definite limits of equivalent-potential temperature have been in use. This seems regrettable for statistical purposes but in practical synoptic work it can hardly be avoided.

It is usually the practice to label the air masses differently on either side of a front, and since polar air is sometimes modified very rapidly, it happens that modified polar air behind a cold front on one weather map may have a higher equivalent-potential temperature than a modified tropical current behind a warm front on a map a week later. Since all tropical air is polar air modified by surface effects, any classification of air masses must be only a compromise as to number of types. The author is of the opinion that no purpose is served by increasing the

ORDER OF DATA  
R.H. T  
q  $\theta_e$   
NO. OF OBS.<sup>2</sup>

**cAw TYPE OF AIR MASS**  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
WINTER 1935-36

	SFC.	500	1000	1500	2000	2500	3000	4000	5000
SHREVE- PORT	63 18	64 272	57 15	59 274	57 15	57 272	54 267	52 265	50 263
BILL- INGS	57 67	57 264	57 264	57 264	57 264	57 264	57 264	57 264	57 264
LAKE- HURST	60 14	59 259	59 12	59 270	59 11	59 273	59 10	59 275	59 276
FARGO	75 05	75 257	75 256	75 253	75 251	75 248	75 245	75 242	75 239
OKLA. CITY	62 13	62 254	62 13	62 250	62 11	62 247	62 12	62 244	62 241
DAY- TON	75 12	75 254	75 12	75 256	75 12	75 258	75 11	75 260	75 262
OMAHA	71 09	71 260	71 10	71 262	71 11	71 264	71 12	71 266	71 268

ORDER OF DATA  
R.H. T  
q  $\theta_e$   
NO. OF OBS.<sup>2</sup>

**mPk TYPE OF AIR MASS**  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
WINTER 1935-36

	SFC.	500	1000	1500	2000	2500	3000	4000	5000
SPO- KANE	85 33	85 270	85 17	85 272	85 17	85 274	85 17	85 276	85 278
OKLA. CITY	71 57	71 259	71 47	71 260	71 34	71 262	71 264	71 266	71 268
FARGO	75 05	75 257	75 256	75 253	75 251	75 248	75 245	75 242	75 239
SE- ATTLE	82 52	82 293	82 47	82 294	82 40	82 295	82 34	82 296	82 297
OMAHA	78 40	78 290	78 38	78 284	78 30	78 286	78 23	78 288	78 290
CHEY- ENNE	71 23	71 261	71 23	71 263	71 23	71 265	71 23	71 267	71 269
BILL- INGS	64 27	64 260	64 27	64 262	64 27	64 264	64 27	64 266	64 268

ORDER OF DATA  
R.H. T  
q  $\theta_e$   
NO. OF OBS.<sup>2</sup>

**cPw TYPE OF AIR MASS**  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
WINTER 1935-36

	SFC.	500	1000	1500	2000	2500	3000	4000	5000
FARGO	87 22	87 270	87 22	87 272	87 22	87 274	87 22	87 276	87 278
MUR- FREES- BORO	75 31	75 281	75 31	75 283	75 31	75 285	75 31	75 287	75 289
OKLA. CITY	73 21	73 278	73 21	73 280	73 21	73 282	73 21	73 284	73 286
OMAHA	87 27	87 270	87 27	87 272	87 27	87 274	87 27	87 276	87 278
PENSA- COLA	74 40	74 280	74 40	74 282	74 40	74 284	74 40	74 286	74 288
DAY- TON	80 24	80 276	80 24	80 278	80 24	80 280	80 24	80 282	80 284
MONT- GOMERY	87 24	87 280	87 24	87 282	87 24	87 284	87 24	87 286	87 288

ORDER OF DATA  
R.H. T  
q  $\theta_e$   
NO. OF OBS.<sup>2</sup>

**mPw TYPE OF AIR MASS**  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
WINTER 1935-36

	SFC.	500	1000	1500	2000	2500	3000	4000	5000
CHEY- ENNE	52 15	52 270	52 15	52 272	52 15	52 274	52 15	52 276	52 278
MONT- GOMERY	72 32	72 278	72 32	72 280	72 32	72 282	72 32	72 284	72 286
FARGO	75 05	75 257	75 256	75 253	75 251	75 248	75 245	75 242	75 239
OKLA. CITY	73 21	73 278	73 21	73 280	73 21	73 282	73 21	73 284	73 286
SE- ATTLE	82 52	82 293	82 47	82 294	82 40	82 295	82 34	82 296	82 297
SPO- KANE	85 33	85 270	85 17	85 272	85 17	85 274	85 17	85 276	85 278
OMAHA	78 40	78 290	78 38	78 284	78 30	78 286	78 23	78 288	78 290

ORDER OF DATA  
R.H. T  
q  $\theta_e$   
NO. OF OBS.<sup>2</sup>

**S TYPE OF AIR MASS**  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
WINTER 1935-36

	SFC.	500	1000	1500	2000	2500	3000	4000	5000
PENSA- COLA	48 52	48 316	48 316	48 316	48 316	48 316	48 316	48 316	48 316
SAN AN- TONIO	58 38	58 309	58 309	58 309	58 309	58 309	58 309	58 309	58 309
OKLA. CITY	55 34	55 292	55 34	55 294	55 34	55 296	55 34	55 298	55 300
SPO- KANE	85 33	85 270	85 17	85 272	85 17	85 274	85 17	85 276	85 278
SHREVE- PORT	77 52	77 295	77 52	77 297	77 52	77 299	77 52	77 301	77 303
BILL- INGS	57 67	57 264	57 67	57 266	57 67	57 268	57 67	57 270	57 272
MONT- GOMERY	87 24	87 280	87 24	87 282	87 24	87 284	87 24	87 286	87 288

ORDER OF DATA  
R.H. T  
q  $\theta_e$   
NO. OF OBS.<sup>2</sup>

**mT TYPE OF AIR MASS**  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
WINTER 1935-36

	SFC.	500	1000	1500	2000	2500	3000	4000	5000
SHREVE- PORT	83 105	83 319	83 105	83 321	83 105	83 323	83 105	83 325	83 327
PENSA- COLA	57 127	57 328	57 127	57 330	57 127	57 332	57 127	57 334	57 336
SAN AN- TONIO	58 111	58 320	58 111	58 322	58 111	58 324	58 111	58 326	58 328
COCO SOLO	88 170	88 345	88 170	88 347	88 170	88 349	88 170	88 351	88 353
ST. THOMAS	84 149	84 337	84 149	84 339	84 149	84 341	84 149	84 343	84 345

FIGURE 12.—Winter values of significant air-mass properties.

ORDER  
OF DATA

R.H. T  
q Be

NO. OF OBS.

CAW TYPE OF AIR MASS

MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
SPRING 1936

SFC.	500	1000	1500	2000	2500	3000	4000	5000
BILLINGS	75 112 1.5 275		75 103 1.3 277	75 107 1.1 278	71 91 0.8 281	61 79 0.2 287		
CHEYENNE	84 23 17 283		65 178 1.9 293	71 142 1.4 297	61 122 1.2 300			
FARGO	81 53 2.0 275	75 55 2.3 277	64 81 1.8 278	55 103 1.3 280	55 140 0.9 292	43 154 0.4 298	43 177 0.2 302	
SPOKANE	73 52 2.1 278		62 18 2.0 285	55 184 1.4 282	55 131 1.0 282	54 107 0.6 289		
KANE								

ORDER  
OF DATA

NO. OF OBS.<sup>2</sup>

MPK TYPE OF AIR MASS

MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
SPRING 1936

	SFC.	500	1000	1500	2000	2500	3000	4000	5000
BILLINGS	58 18 2.7 292			51 27 2.4 294	50 32 1.9 294	50 35 1.6 293	49 42 1.3 291	47 50 0.9 294	47 58 0.4 295
CHEYENNE	67 52 2.2 290			65 57 2.2 291	65 50 1.8 288	66 42 1.4 282	74 21 0.9 293	66 17 0.5 295	
FARGO	64 24 4.0 280	59 39 3.2 280	59 27 2.7 280	54 23 2.0 282	55 20 1.9 281	45 114 1.1 280	46 182 0.8 289	47 213 0.5 293	50 221 0.3 296
OMAHA	65 30 3.2 285	60 37 3.7 285	57 21 2.8 281	56 13 2.3 282	48 42 1.7 282	44 29 1.2 281	40 136 0.9 291	43 215 0.5 292	47 218 0.3 298
SPOKANE	70 33 3.9 292		64 34 3.5 285	62 11 2.9 285	63 16 2.3 284	62 133 1.7 283	61 144 1.2 281	59 127 0.8 282	57 131 0.3 293
KANE									

ORDER OF DATA  
RH T  
q Be  
NO. OF OBS.<sup>2</sup>

**cPw TYPE OF AIR MASS**  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
SPRING 1936

SFC.	500	1000	1500	2000	2500	3000	4000	5000
FARGO	81 51 4.3 283	74 44 4.1 281	53 30 2.6 282	51 05 2.2 284	46 11 2.0 284			
LAKE HURST	71 50 4.0 288	61 42 3.6 280	57 28 3.3 283	49 24 1.9 289	55 49 2.0 293	52 50 1.9 297	24 67 0.8 298	
MURFREESBORO	77 28 5.0 294	71 52 4.6 295	65 34 3.7 295	56 22 2.6 298				
OMAHA	69 72 4.9 286	53 75 4.7 286	61 54 4.0 289	60 41 3.7 282	62 26 3.1 285			
ST. LOUIS	75 58 4.0 281	83 42 3.8 284	74 24 2.9 282	56 23 2.6 290	53 03 1.6 298	23 24 1.0 298		
WASH-INGTON	71 72 4.3 282	48 01 3.0 284	44 18 2.6 287	43 26 2.0 287	55 17 2.4 289	79 74 2.4 286		

ORDER  
OF DATA

NO. OF OBS.<sup>2</sup>

MPW TYPE OF AIR MASS

MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
SPRING 1936

SFC.	500	1000	1500	2000	2500	3000	4000	5000
BILLINGS	57 18 4.1 302		53 30 4.2 304	55 49 3.7 308	56 18 3.1 308	59 17 2.0 309	63 50 1.1 309	54 167 0.4 310
CHEYENNE	61 40 4.1 307		59 44 3.8 308	62 19 3.3 310	65 10 2.8 310	59 27 1.9 310	57 107 1.1 310	
FARGO	81 110 9 306	67 132 11 308	67 105 5.0 309	60 73 4.8 308	58 43 3.9 308	58 32 3.1 307	59 10 2.7 307	59 89 1.9 308
OMAHA	71 100 5.5 301	62 105 5.1 302	60 34 4.1 308	64 45 3.7 313	64 21 2.7 313	50 05 1.6 305	54 37 1.1 308	53 26 1.0 308
SPOKANE	70 74 5.0 303		63 109 5.0 309	58 08 4.9 309	57 52 4.1 309	58 18 3.5 309	64 19 3.0 309	65 17 2.1 310
KANE								
DAYTON	70 94 6.1 301	63 99 5.4 303	62 98 5.0 304	60 50 4.3 304	60 30 3.9 304	58 22 3.0 306	57 31 2.5 306	59 18 1.8 309
OKLA. CITY	50 108 4.3 299	57 114 4.7 301	60 108 4.2 304	67 19 3.8 305	68 57 3.5 304	66 29 3.0 308	61 05 2.8 310	63 68 2.8 311

ORDER  
OF  
DATA

Diagram illustrating the order of data collection: RH (Relative Humidity) and T (Temperature) are measured at the surface (q), and theta\_e (Equivalent Potential Temperature) is measured at a higher level (theta\_e).

NO. OF OBS.

S

TYPE OF AIR MASS

MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES

SPRING 1936

	SFC.	500	1000	1500	2000	2500	3000	4000	5000
EL PASO	24 150 3.0 308			26 133 3.7 315	25 111 3.2 315	24 94 2.8 315	27 28 2.3 305	25 15 1.8 306	25 195 0.9 316
SAN ANTONIO				32 165 3.9 313	28 132 3.5 318	27 97 2.8 315	26 89 2.4 318	26 15 1.5 317	25 139 1.0 318
MONTGOMERY				32 101 3.0 301	27 73 2.7 308	25 44 2.5 308	25 27 1.8 311	22 19 1.3 314	21 108 0.9 317
WASHINGTON				31 148 4.0 308	32 113 3.5 308	22 64 2.5 308	20 37 1.7 305	19 148 1.3 311	20 180 0.9 316
ST. LOUIS				31 164 4.0 308	30 117 3.8 310	29 88 2.9 308	28 67 2.5 311	26 133 1.9 313	26 137 1.0 315
MURFREESBORO				34 185 4.0 308	33 191 3.8 310	32 161 2.9 310	30 137 2.4 313	30 121 1.6 315	29 87 1.0 317
PENSA-COLA				32 145 3.9 307	29 124 3.0 308	28 100 2.5 309	26 68 2.0 313	24 13 1.4 315	21 85 0.9 319

ORDER  
OF  
DATA

NO OF OBS

MT

TYPE OF AIR MASS

MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES

SPRING 1936

SFC.	500	1000	1500	2000	2500	3000	4000	5000
SHREVEPORT	27 197 12.5 327	71 220 108 318	72 23 3.9 318	72 12 3.4 310	69 11 3.1 324	65 81 2.8 322	63 17 2.5 322	64 14 1.7 322
PORT								
EL PASO	50 184 8 327		56 180 8 327	53 13 7 319	55 119 6.2 317	50 84 5.3 317	60 12 3.7 318	64 275 2.0 319
SAN ANTONIO	33 190 11 329	87 200 10.5 331	75 173 10.7 330	68 159 8 328	68 124 7.4 326	61 89 6.2 325	62 60 5.0 323	62 42 3.7 323
TONIO								
MONTGOMERY	86 188 11.5 313	63 211 10.2 317	62 187 9 317	61 150 8.8 326	62 122 8 324	61 122 6.1 324	61 65 5.3 323	58 10 3.6 323
GOMERY								
MURFREESBORO	85 183 11.2 322	64 211 10.1 316	64 184 9.5 317	71 146 8.0 325	74 108 7.4 324	68 79 6.0 322	69 43 5.0 321	62 22 3.4 320
FRESBORO								
OKLA. CITY	87 193 11.8 319	71 191 10.5 315	59 190 8.0 317	60 160 7 322	61 131 6 322	60 99 5.0 325	59 59 4.0 325	63 18 3.4 320
PENSA-COLA	51 207 15.9 331	82 198 11.4 331	79 171 10.7 329	83 119 9.8 329	80 112 8.7 327	77 86 7.2 327	72 57 5.9 325	66 10 4.0 325
COLA								

FIGURE 13.—Spring values of significant air-mass properties.

ORDER OF DATA  
RH T  
q θ<sub>E</sub>

**cP TYPE OF AIR MASS**  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
SUMMER 1936

NO OF OBS	SFC	500	1000	1500	2000	2500	3000	4000	5000
FARGO	71 153 29 312	55 100 27 318	53 071 25 319	52 142 24 319	51 114 23 319	51 080 22 318	50 022 21 316	49 022 20 312	48 021 19 312
BOSTON	77 156 29 312	58 100 27 318	57 051 25 319	62 110 24 317	60 089 23 316	59 068 22 315	58 010 21 314	57 010 20 314	56 010 19 314
OMAHA	63 174 29 312	56 100 27 318	52 071 25 319	50 047 24 317	51 019 23 316	49 010 22 315	48 010 21 314	47 010 20 314	46 010 19 314
ST. LOUIS	74 176 29 312	55 100 27 318	49 051 25 319	49 040 24 317	52 010 23 316	52 010 22 315	51 010 21 314	50 010 20 314	49 010 19 314
DAY-TON	77 156 29 312	58 100 27 318	57 051 25 319	62 110 24 317	60 089 23 316	59 068 22 315	58 010 21 314	57 010 20 314	56 010 19 314
WASH-INGTON	83 187 29 312	51 100 27 318	49 071 25 319	55 135 24 317	57 099 23 316	62 071 22 315	72 061 21 314	72 061 20 314	71 061 19 314
DE-TROIT	81 186 29 312	50 100 27 318	49 071 25 319	52 130 24 317	52 092 23 316	53 056 22 315	53 016 21 314	52 016 20 314	51 016 19 314

ORDER OF DATA  
RH T  
q θ<sub>E</sub>

**mT TYPE OF AIR MASS**  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
SUMMER 1936

NO OF OBS	SFC	500	1000	1500	2000	2500	3000	4000	5000
SPO-KANE	76 180 29 312	62 071 25 319	54 022 24 317	58 010 23 316	58 010 22 315	61 010 21 314	67 010 20 314	76 010 19 314	76 010 18 314
BILL-INGS	55 121 29 312	40 022 24 317	41 010 23 316	45 010 22 315	45 010 21 314	51 010 20 314	65 010 19 314	74 010 18 314	74 010 17 314
CHEY-ENNE	68 160 29 312	40 022 24 317	41 010 23 316	45 010 22 315	45 010 21 314	51 010 20 314	65 010 19 314	74 010 18 314	74 010 17 314
OMAHA	65 160 29 312	40 022 24 317	41 010 23 316	45 010 22 315	45 010 21 314	51 010 20 314	65 010 19 314	74 010 18 314	74 010 17 314
ST. LOUIS	71 156 29 312	55 100 27 318	49 051 25 319	49 040 24 317	52 010 23 316	52 010 22 315	51 010 21 314	50 010 20 314	49 010 19 314
DAY-TON	77 156 29 312	58 100 27 318	57 051 25 319	62 110 24 317	60 089 23 316	59 068 22 315	58 010 21 314	57 010 20 314	56 010 19 314
WASH-INGTON	83 187 29 312	51 100 27 318	49 071 25 319	55 135 24 317	57 099 23 316	62 071 22 315	72 061 21 314	72 061 20 314	71 061 19 314

ORDER OF DATA  
RH T  
q θ<sub>E</sub>

**mP TYPE OF AIR MASS**  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
SUMMER 1936

NO OF OBS	SFC	500	1000	1500	2000	2500	3000	4000	5000
FARGO	73 188 29 312	39 022 24 317	39 022 24 317	45 051 25 319	51 023 23 316	57 010 22 315	61 010 21 314	59 010 20 314	58 010 19 314
SPO-KANE	66 157 29 312	54 100 27 318	52 071 25 319	51 044 24 317	57 010 23 316	59 010 22 315	58 010 21 314	57 010 20 314	56 010 19 314
BILL-INGS	53 109 29 312	47 051 25 319	48 040 24 317	48 040 24 317	52 010 23 316	52 010 22 315	51 010 21 314	50 010 20 314	49 010 19 314
CHEY-ENNE	64 156 29 312	47 051 25 319	48 040 24 317	48 040 24 317	52 010 23 316	52 010 22 315	51 010 21 314	50 010 20 314	49 010 19 314
OMAHA	68 160 29 312	47 051 25 319	48 040 24 317	48 040 24 317	52 010 23 316	52 010 22 315	51 010 21 314	50 010 20 314	49 010 19 314

ORDER OF DATA  
RH T  
q θ<sub>E</sub>

**mT TYPE OF AIR MASS**  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
SUMMER 1936

NO OF OBS	SFC	500	1000	1500	2000	2500	3000	4000	5000
EL PASO	56 123 29 312	53 071 25 319	53 071 25 319	56 100 27 318	56 100 27 318	60 100 27 318	69 100 27 318	75 100 27 318	75 100 27 318
SAN AN-TONIO	91 207 29 312	86 153 27 318	73 125 24 317	73 125 24 317	67 088 23 316	63 045 22 315	60 010 21 314	60 010 20 314	60 010 19 314
OKLA-CITY	64 148 29 312	60 100 27 318	53 071 25 319	53 071 25 319	53 071 25 319	52 042 24 317	54 010 23 316	58 010 22 315	58 010 21 314
SHREVE-PORT	81 165 29 312	66 125 24 317	62 088 23 316	62 088 23 316	64 100 27 318	61 067 26 319	57 032 25 319	56 010 24 317	61 010 23 316
PENSA-COLA	91 240 29 312	76 184 27 318	73 154 26 319	74 181 27 318	71 152 26 319	70 123 25 319	67 095 24 317	68 064 23 316	65 027 22 315
MONT-GOMERY	87 226 29 312	68 153 27 318	64 122 26 319	67 193 27 318	65 160 26 319	64 129 25 319	61 099 24 317	61 064 23 316	53 021 22 315
MUR-FREESBORO	89 257 29 312	65 125 24 317	63 095 23 316	63 095 23 316	66 170 26 319	65 138 25 319	60 107 24 317	63 065 23 316	60 037 22 315

ORDER OF DATA  
RH T  
q θ<sub>E</sub>

**S TYPE OF AIR MASS**  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
SUMMER 1936

NO OF OBS	SFC	500	1000	1500	2000	2500	3000	4000	5000
FARGO	43 156 29 312	36 100 27 318	33 071 25 319	31 044 24 317	31 044 24 317	35 010 23 316	35 010 22 315	39 010 21 314	30 010 20 314
CHEY-ENNE	48 162 29 312	47 051 25 319	47 051 25 319	47 051 25 319	47 051 25 319	47 051 25 319	47 051 25 319	47 051 25 319	47 051 25 319
OMAHA	44 123 29 312	36 100 27 318	33 071 25 319	31 044 24 317	31 044 24 317	35 010 23 316	35 010 22 315	39 010 21 314	30 010 20 314
WASH-INGTON	26 123 29 312	23 071 25 319	23 071 25 319	23 071 25 319	23 071 25 319	23 071 25 319	23 071 25 319	23 071 25 319	23 071 25 319
PENSA-COLA	28 123 29 312	23 071 25 319	23 071 25 319	23 071 25 319	23 071 25 319	23 071 25 319	23 071 25 319	23 071 25 319	23 071 25 319
MONT-GOMERY	47 123 29 312	36 100 27 318	33 071 25 319	31 044 24 317	31 044 24 317	35 010 23 316	35 010 22 315	39 010 21 314	30 010 20 314
MUR-FREESBORO	47 123 29 312	36 100 27 318	33 071 25 319	31 044 24 317	31 044 24 317	35 010 23 316	35 010 22 315	39 010 21 314	30 010 20 314

FIGURE 14.—Summer values of significant air-mass properties.

ORDER  
OF DATA

# CAW TYPE OF AIR MASS

## MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES

AUTUMN 1936

	SFC	500	1000	1500	2000	2500	3000	4000	5000
FARGO	73 1.25 2.5 1.279	68 1.10 (41) 2.5 1.283	66 1.25 (38) 2.5 1.285	57 1.30 (20) 2.5 1.290	52 1.43 (15) 2.5 1.292	51 1.57 (15) 2.5 1.293	42 1.14 (10) 2.5 1.293		
BOSTON	68 1.22 3.4 1.283	61 1.08 (2) 2.9 1.285	58 1.17 (23) 2.9 1.286	50 1.28 (2) 2.9 1.289	58 1.47 (2) 1.5 1.290	44 1.78 (13) 1.3 1.292			
OMAHA	78 1.13 3.5 1.285	68 1.23 (4) 3.3 1.288	66 1.22 (2) 3.0 1.290	58 1.17 (2) 2.3 1.291	54 1.35 (2) 2.0 1.294	53 1.59 (2) 1.3 1.295	54 1.84 (2) 1.4 1.298		
DAY- TON	87 1.11 3.8 1.285	76 1.14 (4) 3.4 1.287	70 1.04 (2) 2.8 1.289	53 1.13 (2) 2.1 1.291	52 1.46 (1) 1.8 1.292	38 1.54 (2) 1.2 1.295			
SAULT STE. MARIE	78 1.28 (35) 3.4 1.283	74 1.22 (4) 3.1 1.284	75 1.37 (18) 3.3 1.285	61 1.54 (5) 1.9 1.287	52 1.72 (2) 1.5 1.289	43 1.97 (1) 1.1 1.290	34 1.129 (2) 0.6 1.291	23 1.128 (1) 0.5 1.302	

ORDER OF DATA  
RH T  
q 9e

MPK TYPE OF AIR MASS  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
AUTUMN 1936

NO OF OBS.	SFC.	500	1000	1500	2000	2500	3000	4000	5000
SPO- KANE	80 1.05 4.7 1.280	77 1.13 (2) 4.7 1.280	77 1.13 (2) 4.7 1.280	57 1.19 (2) 4.7 1.280	50 1.49 (2) 4.7 1.280	50 1.05 (2) 4.7 1.280	61 1.25 (2) 4.7 1.280	51 1.01 (2) 4.7 1.280	50 1.10 (2) 4.7 1.280
FARGO	64 1.50 4.6 1.291	64 1.03 (2) 4.6 1.290	56 1.15 (2) 3.6 1.290	51 1.32 (2) 4.2 1.290	47 1.03 (2) 4.2 1.290	47 1.27 (2) 4.2 1.290	50 1.29 (2) 1.8 1.302	48 1.11 (2) 1.6 1.300	45 1.210 (2) 0.6 1.300
BILL- INGS	55 1.62 3.7 1.299			56 1.09 (2) 4.0 1.305	52 1.22 (2) 3.8 1.308	61 1.07 (2) 2.3 1.304	61 1.08 (2) 2.3 1.303	64 1.23 (2) 1.6 1.304	58 1.204 (2) 0.8 1.304
CHEY- ENNE	67 1.08 3.7 1.300			67 1.17 (2) 3.4 1.304	61 1.05 (2) 3.2 1.300	66 1.33 (2) 2.7 1.305	55 1.070 (2) 1.4 1.304	50 1.159 (2) 0.7 1.304	
SALT LAKE CITY	75 1.20 3.1 1.290			56 1.51 (2) 3.0 1.302	51 1.37 (2) 3.2 1.304	51 1.12 (2) 2.7 1.304	56 1.44 (2) 2.3 1.304	60 1.134 (2) 1.4 1.302	47 1.202 (2) 0.7 1.304

ORDER OF DATA  
RH T  
q 9e

CP TYPE OF AIR MASS  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
AUTUMN 1936

NO OF OBS.	SFC.	500	1000	1500	2000	2500	3000	4000	5000
EL PASO	58 1.94 4.9 1.307			53 1.15 (2) 5.1 1.313	55 1.09 (2) 4.8 1.314	47 1.75 (2) 4.1 1.316	54 1.55 (2) 4.2 1.320		
FARGO	76 1.149 8.7 1.304	58 1.12 (2) 7.8 1.316	54 1.154 (2) 6.8 1.317	43 1.130 (2) 5.2 1.316	43 1.17 (2) 4.0 1.314	38 1.79 (2) 3.5 1.316	42 1.45 (2) 3.2 1.316	35 1.12 (2) 2.0 1.318	
OMAHA	77 1.122 6.9 1.306	64 1.15 (2) 6.5 1.308	55 1.138 (2) 7.9 1.312	58 1.109 (2) 5.5 1.313	48 1.05 (2) 4.3 1.312	47 1.76 (2) 4.0 1.315	60 1.48 (2) 4.5 1.320		
DE- TROIT	87 1.138 9.0 1.312	65 1.155 (2) 7.7 1.314	56 1.137 (2) 6.3 1.314	43 1.115 (2) 5.0 1.313	46 1.06 (2) 4.1 1.312	44 1.57 (2) 3.4 1.318	52 1.18 (2) 3.3 1.314		
SAULT STE. MARIE	89 1.112 7.7 1.307	73 1.122 (2) 6.9 1.304	63 1.119 (2) 6.2 1.312	56 1.102 (2) 5.4 1.313	48 1.73 (2) 4.1 1.311	50 1.35 (2) 3.9 1.315	60 1.08 (2) 3.5 1.315	51 1.62 (2) 2.3 1.313	49 1.114 (2) 1.5 1.316
WASH- INGTON	85 1.158 10.2 1.316	62 1.157 (2) 7.3 1.312	58 1.136 (2) 6.2 1.312	59 1.135 (2) 5.3 1.312	65 1.05 (2) 4.9 1.312	58 1.52 (2) 4.3 1.315	59 1.25 (2) 3.5 1.314	59 1.13 (2) 3.2 1.320	

ORDER OF DATA  
RH T  
q 9e

MPW TYPE OF AIR MASS  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
AUTUMN 1936

NO OF OBS.	SFC.	500	1000	1500	2000	2500	3000	4000	5000
SPO- KANE	77 1.133 7.7 1.313		59 1.139 (2) 6.5 1.314	53 1.126 (2) 5.7 1.318	57 1.05 (2) 5.3 1.317	60 1.69 (2) 4.9 1.318	59 1.27 (2) 4.2 1.319	54 1.26 (2) 2.7 1.318	58 1.04 (2) 1.3 1.319
FARGO	82 1.141 8.6 1.313	57 1.198 (2) 8.5 1.322	44 1.183 (2) 5.9 1.319	45 1.180 (2) 5.0 1.315	48 1.05 (2) 4.7 1.313	50 1.55 (2) 3.6 1.314	54 1.18 (2) 3.3 1.315	53 1.53 (2) 2.3 1.315	60 1.127 (2) 1.5 1.315
BILL- INGS	55 1.127 3.9 1.312		46 1.124 (2) 5.2 1.315	43 1.173 (2) 4.5 1.317	45 1.01 (2) 4.1 1.317	53 1.38 (2) 3.7 1.317	55 1.73 (2) 2.8 1.318	55 1.08 (2) 1.5 1.320	
OMAHA	87 1.108 11.5 1.325	65 1.108 (2) 8.7 1.326	54 1.164 (2) 6.9 1.318	46 1.161 (2) 5.4 1.317	45 1.12 (2) 5.0 1.315	49 1.52 (2) 3.7 1.315	50 1.57 (2) 3.1 1.314	50 1.57 (2) 2.1 1.313	50 1.131 (2) 1.2 1.313
SALT LAKE CITY	64 1.08 (2) 3.0 1.308		53 1.118 (2) 5.1 1.313	43 1.07 (2) 4.3 1.313	52 1.55 (2) 3.9 1.312	54 1.11 (2) 3.2 1.313	58 1.62 (2) 2.2 1.313	52 1.128 (2) 1.3 1.304	
OKLA. CITY	82 1.108 6.9 1.305	72 1.117 (2) 6.8 1.308	67 1.138 (2) 6.2 1.313	60 1.11 (2) 5.4 1.312	53 1.17 (2) 4.7 1.314	57 1.05 (2) 4.2 1.315	51 1.36 (2) 3.5 1.315	55 1.57 (2) 2.6 1.317	49 1.07 (2) 1.7 1.320

ORDER OF DATA  
RH T  
q 9e

S TYPE OF AIR MASS  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
AUTUMN 1936

NO OF OBS.	SFC.	500	1000	1500	2000	2500	3000	4000	5000
SPO- KANE			45 1.172 (2) 6.1 1.317	33 1.169 (2) 4.9 1.319	30 1.150 (2) 4.2 1.321	25 1.110 (2) 3.0 1.321	27 1.02 (2) 2.5 1.317	27 1.02 (2) 1.8 1.318	2.6 1.71 (2) 1.1 1.319
MIAMI				34 1.132 (2) 3.9 1.319	29 1.119 (2) 3.3 1.319	27 1.26 (2) 2.7 1.319	24 1.28 (2) 2.1 1.319	23 1.24 (2) 1.2 1.324	
EL PASO			31 1.167 (2) 4.5 1.317	28 1.155 (2) 2.9 1.320	28 1.113 (2) 3.2 1.318	26 1.73 (2) 2.5 1.317	21 1.14 (2) 1.5 1.319	18 1.52 (2) 1.0 1.322	
PENSA- COLA			23 1.119 (2) 4.0 1.317	22 1.121 (2) 2.7 1.314	20 1.103 (2) 2.1 1.314	19 1.73 (2) 1.7 1.319	18 1.21 (2) 1.2 1.319	15 1.30 (2) 0.8 1.323	
OMAHA		31 1.110 (2) 5.5 1.320	30 1.105 (2) 4.3 1.317	30 1.10 (2) 3.4 1.318	30 1.08 (2) 2.9 1.315	30 1.52 (2) 2.4 1.315	28 1.10 (2) 1.5 1.315	26 1.89 (2) 0.7 1.315	
OAK- LAND		30 1.203 (2) 5.5 1.313	27 1.151 (2) 4.5 1.313	27 1.151 (2) 3.3 1.313	26 1.112 (2) 2.7 1.311	26 1.09 (2) 2.2 1.312	23 1.52 (2) 1.8 1.315	21 1.09 (2) 1.2 1.315	22 1.78 (2) 0.8 1.317
MUR- FREES BORO		28 1.106 (2) 4.0 1.303	27 1.103 (2) 2.4 1.307	23 1.107 (2) 1.9 1.309	23 1.44 (2) 1.7 1.311	21 1.11 (2) 1.3 1.315	20 1.05 (2) 0.8 1.318		

ORDER OF DATA  
RH T  
q 9e

MT TYPE OF AIR MASS  
MEAN SEASONAL VALUES OF SIGNIFICANT PROPERTIES  
AUTUMN 1936

NO OF OBS.	SFC.	500	1000	1500	2000	2500	3000	4000	5000
MIAMI	30 1.232 (2) 15.8 1.341	81 1.216 (2) 15.0 1.345	72 1.204 (2) 12.7 1.339	74 1.173 (2) 10.9 1.335	75 1.144 (2) 9.7 1.334	67 1.124 (2) 8.1 1.333	67 1.07 (2) 7.1 1.333	65 1.40 (2) 5.3 1.333	61 1.18 (2) 3.6 1.332
OKLA. CITY	74 1.240 (2) 14.1 1.341	70 1.243 (2) 14.0 1.342	52 1.238 (2) 12.7 1.343	60 1.195 (2) 11.0 1.342	55 1.165 (2) 9.7 1.338	64 1.133 (2) 8.2 1.335	65 1.171 (2) 7.1 1.334	63 1.35 (2) 5.0 1.332	58 1.23 (2) 3.4 1.332
PENSA- COLA	50 1.218 (2) 15.1 1.335	79 1.224 (2) 14.0 1.339	70 1.194 (2) 12.0 1.336	79 1.165 (2) 10.3 1.335	73 1.139 (2) 9.2 1.333	69 1.115 (2) 7.8 1.332	67 1.09 (2) 6.7 1.331	68 1.29 (2) 5.1 1.331	65 1.27 (2) 3.8 1.333
EL PASO	68 1.197 (2) 11.0 1.337		64 1.227 (2) 10.0 1.335	62 1.193 (2) 9.2 1.335	75 1.144 (2) 8.0 1.335	75 1.113 (2) 6.4 1.335	74 1.42 (2) 5.1 1.335	70 1.17 (2) 3.4 1.332	
SAN AN- TONIO	96 1.223 (2) 14.5 1.344	80 1.225 (2) 13.9 1.344	70 1.205 (2) 12.0 1.335	77 1.151 (2) 10.7 1.335	69 1.152 (2) 9.1 1.334	68 1.127 (2) 8.1 1.334	67 1.07 (2) 7.0 1.333	65 1.41 (2) 5.4 1.332	68 1.24 (2) 3.9 1.332
SHREVE- PORT	87 1.214 (2) 15.6 1.338	75 1.238 (2) 14.5 1.342	73 1.217 (2) 13.7 1.341	75 1.185 (2) 11.0 1.340	74 1.150 (2) 9.7 1.332	66 1.170 (2) 7.7 1.332	65 1.15 (2) 6.8 1.330	68 1.34 (2) 5.1 1.330	45 1.07 (2) 3.0 1.332
MONT- GOMERY	91 1.217 (2) 14.7 1.335	70 1.218 (2) 13.7 1.337	70 1.215 (2) 11.8 1.336	72 1.173 (2) 10.3 1.334	64 1.149 (2) 8.5 1.334	60 1.119 (2) 6.9 1.330	63 1.08 (2) 6.1 1.330	65 1.00 (2) 4.8 1.330	68 1.26 (2) 3.5 1.331

FIGURE 15.—Autumn values of significant air-mass properties.

number of types. The three main air masses, cA, mA, and mT have definite distinguishable properties; but the modified and mixed forms of these air masses may assume an entirely different set of characteristics. Further, since the relative dryness of an air mass is sometimes considered in its classification, the effects of pressure distribution alone may cause a change in label for the air mass.

The use of equivalent-potential temperature identifies the amount of heat and moisture in an air mass, and the relative humidity gives an indication of the degree of saturation. It has been suggested that a classification system be adopted using only the above two properties as arguments. The major objections to such a system are that the number of possible combinations becomes too large, it has no geographical significance, and it gives no indication of vertical stability. Therefore it seems advisable to continue the use of the three major types Pc, Pp, and Tm, since they immediately convey indications of heat and moisture content and of vertical stability. In the wintertime the notations NpA, Npp, and Ntm also appear satisfactory. Tp is rare in occurrence in the United States, especially in the summer, and its properties must be very similar to Ta air, so it seems advisable to use only the symbol Tm for all tropical maritime air masses. PA is also rare at coastal stations but it often goes all the way around a Hudson Bay cyclone and enters the United States from the north. The characteristic properties of PA and Pp should not be appreciably different, so only the symbol Pm should be used in such cases since there is often a current of Pp air flowing parallel to the PA current. Whenever there is reason to believe that Pc and any polar maritime air mass have been mixed by mechanical turbulence or by convection, the notation Pc should be used since most of the maritime characteristics have probably disappeared.

In midsummer all polar air masses are so rapidly modified over the continent that it seems advisable to use only the symbol Np for all polar air masses over the continental United States at that season. At all seasons when a polar air mass is rapidly assuming tropical maritime characteristics it is suggested that it be called Npm. A study of samplings of Npp→Tp, Npp→Tm, Np→Ta, Np→Tm, PA→NpA, NpC→Ta, and Np→Ta shows no definite distinguishable properties and all of these air masses can be called Npm and still have as much practical synoptic significance.

It seems necessary to continue the use of the symbol S to describe dry subsiding air masses. As soon as the air mass shows signs of being lifted the symbol S should be dropped since it would then be very misleading. The use of the notation Nps is suggested for polar air masses apparently in the early stages of subsidence.

In summary, the use of the following air mass types is considered of practical synoptic significance for the United States: For most of the year: Pc, PA, Pp, Pm, NpC, Npp, Npm, Nps, Tm, and S. For midsummer: Np, Npm, Nps, Tm, and S. However, since the above labels do not identify the stability of the lower levels of the air mass, it has been recommended that the differential classification of Bergeron be adopted as explained in an earlier paragraph.

#### THE AIR MASS CYCLE

Following the above-suggested classification it is possible to identify two distinct cycles of transition from polar to tropical air, one a moist cycle with rapid addition of moisture, the other a dry cycle with a marked subsidence and slow isentropic mixing in the early stages. An attempt

to identify these cycles for the winter and summer seasons has been made on figures 8 to 11.

For the winter season the moist transitional stage, figure 8, from mP as represented at Dayton, to Tm at Pensacola and St. Thomas, shows continual subsidence and increasing moisture. The persistent stability throughout the transitional process, the difference in potential temperature between 500 m. and 5,000 m. remaining practically constant from the mA to the Tm stage, indicates that the principal addition of moisture must occur by means of mixing along isentropic surfaces, with some probability of convection in the final mT stage.

The dry winter cycle, figure 9, shows rapid subsidence with slight increase of moisture by isentropic mixing from the mA to the S stage. When this air mass moves to lower latitudes the subsidence decreases, rapid surface heating develops and the S air begins to mix both vertically and horizontally with mT air. The vertical mixing is probably confined to the lowest layers affected by daytime convection and most of the increase in moisture aloft appears to be due to isentropic mixing.

The identification of the moist and dry cycles is more difficult in the summer season because of the greater tendency for vertical convection during the day, with convection occurring under saturated conditions which cannot be analyzed by charts using potential temperature surfaces. However, the mean values, indicating unsaturated conditions, suggest for the moist cycle conditions similar to those observed in the winter season, namely, subsidence and surface heating with rapid increase of moisture by isentropic mixing.

The dry cycle for summer is more difficult to identify because the driest stage, S at Omaha, as shown in individual cases, is not clearly shown by the mean values for S at that station. In other words, some of the flights used in computing means for S air at Omaha may represent returning subsiding tropical maritime currents.

Examination of the mean isentropic chart for mT air in summer shows the tongue of air with highest moisture content to be probably subsiding as it moves northeastward from El Paso to Omaha. The apparent upward slope of the isentropic surfaces from Omaha to Pensacola is partly due to convergence and daytime convection over the Gulf coastal regions. The mT air at El Paso represents a more advanced stage of development than mT at Pensacola. The flow pattern suggested by the mean isentropic chart for summer mT indicates that the immediate trajectory of the mT air at El Paso is from the lower Caribbean area. The study indicates that appreciable quantities of heat and moisture may be added to mT air over the continental United States. The highest value of equivalent potential temperature, 366° A., observed during this study was found at 1,000 m. at Dayton on August 22, 1936.

The dry cycle in summer then represents rapid modification of the polar air masses with subsidence aloft and slow addition of moisture by isentropic mixing over the continent, then continued heating accompanied by vertical convection and convergence over the Gulf and Caribbean, followed by a slow spreading out and subsidence as the air assumes an anticyclonic trajectory on its return from the lower Caribbean to El Paso. From El Paso to the Mississippi Valley there is apparently a continued addition of heat and moisture and the mT air again becomes convectively unstable over the Mississippi and Ohio Valleys.

In the identification of air masses aloft in practical synoptic work it is recommended that attention be paid to the mean seasonal values for each of the principal air

mass types and also to the probable range of equivalent-potential temperatures. In view of recent discoveries of the meteorological significance of isentropic charts it is further recommended that more attention be given to the slope of potential temperature surfaces in situations free from condensation. Allowance should be made for the possibility of horizontal mixing on isentropic surfaces and unless the isentropic surfaces in one air mass actually intersect the ground or at least show a sudden increase in slope, the synoptic analyst should label the air masses differently with caution.

## BIBLIOGRAPHY

- (1) Willet, H. C., *American Air Mass Properties*. Mass. Inst. of Tech. Papers in Physical Oceanography and Meteorology, vol. II, No. 2.
- (2) Willet, H. C., *Definition of Ts as Employed by the Massachusetts Institute of Technology*.
- (3) Bergeron, Tor. *Über die dreidimensional verknüpfende Wetteranalyse*. Geofysiske Publikasjoner, vol. V. No. 6.
- (4) Byers, H. R., *Synoptic and Aeronautical Meteorology*. McGraw-Hill, 1937.
- Byers, H. R., *Characteristic Weather Phenomena of California*. M. I. T., Meteorological Papers, vol. I, No. 2.
- (5) Wexler, H., *Cooling in the Lower Atmosphere and the Structure of Polar Continental Air*. MONTHLY WEATHER REVIEW, vol. 64, April 1936.
- (6) Rossby, C.-G. and Collaborators, *Aerological Evidence of Large-Scale Mixing in the Atmosphere*. Transactions, American Geophysical Union, part I, Section of Meteorology, April 1937.
- Rossby, C.-G. and Collaborators, *Isentropic Analysis*. Bulletin American Meteorological Society, vol. 18, June-July 1937.
- (7) Pilot Charts of the North Pacific Ocean, U. S. Hydrographic Office.
- (8) McDonald, W. F., and Showalter, A. K., *Air and Water Temperatures in the West Indian Region*. Transactions, American Geophysical Union, Section of Oceanography, April 1933.
- (9) Deppermann, Rev. C. E., *The Upper Air at Manila*. Publications of the Manila Observatory, vol. II, No. 5.
- (10) Rossby, C.-G., *Thermodynamics Applied to Air Mass Analysis*. M. I. T., Meteorological Papers, vol. I, No. 3.

## NOTES AND REVIEWS

JOHN G. ALBRIGHT. *Physical Meteorology*. New York (Prentice-Hall), 1939. xxx, 392 pp., 246 figs.

This book, as implied by the title, emphasizes the physical rather than the descriptive or statistical aspects of meteorology; it is primarily an elementary exposition of the fundamental physical laws to which atmospheric phenomena conform, and an application of these laws to the explanation of the more important physical phenomena of the atmosphere. The book is intended as an introductory college textbook. It presupposes a working knowledge of physics, although a chapter on the principles of the theory of heat is included. The treatment is essentially nonmathematical, but a number of simple mathematical formulae are quoted and derivations are given for most of them.

The introductory chapter is devoted to a description of the scope of meteorology and its place among the sciences,

with a brief historical sketch. After a chapter on the atmosphere in general, the succeeding chapters consider in detail, barometric pressure, temperature, insolation, and atmospheric water vapor. A chapter on the thermodynamics of the atmosphere includes a discussion of lapse rates and stability; and is followed by chapters on the wind, the dynamic theory of air movements, and a brief description of the planetary circulation. Consideration is next given to condensation, clouds, and the various forms of precipitation, followed by two chapters on tropical and extratropical cyclones, including a description of tornadoes and brief reference to the methods of air-mass analysis. The book is concluded by chapters on atmospheric electricity (including the aurora), thunderstorms and lightning, atmospheric acoustics, and atmospheric optics.—*Edgar W. Woolard.*

## BIBLIOGRAPHY

[RICHMOND T. ZOCH, in Charge of Library]

By AMY P. LESHER

## RECENT ADDITIONS

The following have been selected from among the titles of books recently received as representing those most likely to be useful to Weather Bureau officials in their meteorological work and studies:

Abbot, Charles Greeley.

Utilizing heat from the sun. Washington, D. C. 1939. 11 p. 4 pl., diagr. 24½ cm. (Smithsonian miscellaneous collections. v. 98, no. 5.) Publication 3530.

Brezina, E., & others.

Klima-Wetter-Mensch, von E. Brezina, W. Hellpach, R. Hesse, E. Martini, B. de Rudder, A. Schittenhelm, A. Seybold, L. Weickmann. Herausgegeben von Heinz Woltereck. Leipzig. 1938. 446 p. illus., maps, tabs., diagrs. 25½ cm.

Bullen, K. E.

A method of smoothing time series of data with application to annual rainfalls at Auckland, Wellington, N. Z. 1939. 139 B-144B p. tables, diagr. 28 cm. (Extracted from the New Zealand journal of science and technology. v. 20, no. 3B. 1938.)

Desaunais, A.

La crue de l'Ain et de la Valserine en Octobre 1935. [Lyon. 1938.] p. 88-92. map. 24½ cm. (From Les études rhodaniennes, Revue de géographie régionale, publiée à l'Institut des études rhodaniennes de l'Université de Lyon. v. 14, no. 1. 1938.)

The desert magazine. March, 1938. 1 v. 30 cm.

McKenney, J. Wilson. Yuma's sunshine reporter. p. 19, 26.

Eredia, Filippo.

Il clima, e, in particolare, le correnti aeree della Libia. Rome. 1937. 10 p. tables. 30½ cm.

Flaig, Walther.

Das Gletscherbuch. Rätsel und Romantik, Gestalt und Gesetz der Alpenglletscher. Leipzig. 1938. 196 p. illus., plates, tables. 23½ cm.

Fotos, John Theodore, & Bray, John L.

German grammar for chemists and other science students; with simple graded readings based on vocabulary and syntax frequency studies. New York & London. 1938. xxii, 323 p. 21 cm.